Environmental effects monitoring (EEM) is a requirement for pulp and paper mills in Canada discharging effluent directly into receiving environments under the Pulp and Paper Effluent Regulations of the *Fisheries Act*. The objective of the EEM program is to assess effects on fish, fish habitat and the use of fisheries resources by humans, potentially affected by the deposit of mill effluent in aquatic receiving environments. The information provided by the monitoring program will contribute to assessing the adequacy of the regulations. Difficulties encountered in the first round of monitoring led to an extensive science review of key components and resulted in improvement to process, scientific defensibility of the monitoring data and site-specific flexibility of the EEM program. The second cycle of EEM was, overall, markedly more successful than Cycle 1. However, problems were still evident for fish surveys conducted in marine and estuarine environments. The adoption of improved alternative monitoring approaches (e.g., caged bivalves, mesocosms) should alleviate many of these problems. An overview of the EEM program, results to date, alternative monitoring approaches, and research priorities to fill data gaps are presented.

**Key words:** monitoring, pulp mills, fish, benthic invertebrates, tainting, dioxins

**Introduction**

Studies conducted in the early 1990s downstream of pulp and paper mills in Canada found a number of changes in the physiological, biochemical and reproductive responses of wild fish (Hodson et al. 1992; McMaster et al. 1991; Munkittrick et al. 1991, 1992). As a result of these and other studies, an assessment led to bleached pulp and paper mill effluents being declared “toxic” to the environment under the *Canadian Environmental Protection Act* Section 11(a) (Government of Canada 1991). Further studies (Munkittrick et al. 1994) were not able to correlate the physiological and reproductive responses in fish downstream of mills with the use of chlorine bleaching or the presence of secondary treatment and concluded that other factors in the effluents were likely responsible for the effects detected in wild fish populations.

As a result of the changes in aquatic environments receiving pulp and paper mill effluents, the 1971 Pulp and Paper Effluent Regulations (PPER) under the *Fisheries Act* were amended in 1992 based on pollution
control technology to include more stringent limits on effluent discharge for biochemical oxygen demand and total suspended solids as well as acute lethality to rainbow trout. While revisiting the PPER, regulators acknowledged the variability and abundance of parameters in mill discharges as well as the great diversity of aquatic receiving environments and concluded that uniform limits for a few parameters in the effluent may not necessarily protect the health of all aquatic receiving environments across Canada. In order to address these issues, a key component of the PPER was the introduction of a requirement for mills to conduct environmental effects monitoring (EEM) in sections 28 to 35. The specific requirements are detailed in an annex to the regulation (AEEMR 1992) with scientific guidance provided in companion documents (EC/DFO 1993; DFO/EC 1995a,b; Environment Canada 1998).

The 1992 PPER was Canada’s first national regulatory program to include an EEM requirement. The inclusion of EEM as a regulatory requirement represented a significant step forward in environmental regulation in Canada by moving from a traditional end-of-pipe approach of managing industrial discharges to an iterative monitoring, assessment and management approach. In other words, the PPER represented a vital advance to industrial regulation in Canada by including EEM as an assessment of the health of aquatic ecosystems directly in ambient environments receiving industrial discharges. More critically, EEM was built directly into the PPER as a science-based feedback loop to help assess the effectiveness of this environmental protection measure.

This issue of the Water Quality Research Journal of Canada is dedicated to the publication of articles on the theme of scientific issues associated with the EEM program. The purpose of this paper is to provide an overview of the EEM program for the pulp and paper sector to set the context and provide background information for the related articles in this issue. Further details of the EEM program are available on the EEM web site (http://www.ec.gc.ca/eem).

Overview of the EEM Program

The objective of the EEM program is to evaluate the effects of pulp and paper effluent on fish, fish habitat and the use of fisheries resources by humans. This information will be used to help assess the adequacy of the regulations to effectively protect these aquatic resources on the basis of the magnitude and spatial extent of effects in receiving environments that are related to mill discharges.

The EEM program for pulp and paper mills is structured into three- or four-year sequences of monitoring and interpretation phases called cycles. At the beginning of each cycle, each mill designs a site-specific field monitoring study utilizing the results of a site characterization included in the pre-design information requirements and any previous monitoring data. At the end of each study, the mill is required to submit an interpretative report and supporting data to Environment Canada.
The first pulp and paper EEM cycle, completed in April 1996, was intended to establish a baseline against which data from future cycles could be compared, and to provide a preliminary assessment of whether effects, if any, are evident in the receiving environment. A number of scientific and technical issues arose in Cycle 1. An extensive scientific review of Cycle 1 resulted in a number of improvements to the EEM program. This review necessitated a one-year extension for Cycle 2, which was completed in April 2000. Cycle 3 is in progress with results anticipated in April 2004.

The requirements of the EEM program may include the following key components: a fish survey to assess effects on fish; a benthic invertebrate community survey to assess effects on fish habitat; and a tainting study and analyses of dioxins and furans in edible fish tissue to assess effects on the usability of fisheries resources. Other EEM requirements are used to interpret the effects (supporting environmental variables) or help characterize changes in effluent quality over time (sublethal toxicity testing). As well, a chemical tracer may also be required to help assess fish exposure to mill effluent and identify appropriate reference areas. Comprehensive descriptions of the above monitoring components are found in Environment Canada (1998).

For the purposes of EEM, an effect is generally defined as a statistically significant difference in fish, benthic invertebrate community, or tainting endpoints measured between an area exposed to effluent and a reference area or a statistically significant gradient in these endpoints from the exposure to reference areas. For fish tissue analysis, which is used to assess effects on the usability of fisheries resources, human health consumption guidelines for dioxins and furans set by the applicable regulatory agency are used as the benchmark for data interpretation.

Issues and Challenges

As a result of a number of scientific and technical issues identified during Cycle 1, an extensive science review was conducted to identify problems and provide recommendations for modifications to the program for subsequent cycles. Expert working groups (EWG) were established to address these concerns and make recommendations for various components of the program including the fish survey, benthic invertebrate community survey, usability of resources (tainting), dioxins and furans in edible fish tissue, toxicology and tracers. The EWG were comprised of individuals from government (Environment Canada and Fisheries and Oceans Canada), consulting companies, academia, aboriginal representation and industry. Recommendations from these groups resulted in a number of changes to the program and were incorporated into a revised technical guidance document for the pulp and paper EEM program (Environment Canada 1998). These changes have improved the quality of the monitoring data for Cycle 2 and subsequent cycles through better scientific methodology and increased flexibility by allowing for the consideration of site-specific conditions.
Fish Survey

One of the primary components of the EEM program is the fish survey, which monitors the growth, reproduction and condition of fish populations in waters receiving mill effluent. Specific fish measurements reflect the energy use (growth rate, gonad weight, fecundity, age at maturity), energy storage (condition, liver weight) and age (mean age or age distribution) of two sentinel fish species (Munkittrick et al. 2002).

The objective of the first cycle of EEM was to collect baseline information (i.e., fish species selected, capture techniques, sampling areas) and to determine variability in fish measurements. The objective of the second and subsequent cycles was to confirm any differences found, determine the extent and magnitude of these differences, and identify causes.

In Cycle 1, the fish survey was poorly conducted at many mills. The key issues associated with Cycle 1 that were identified by the Fish Survey EWG included: inability to catch sufficient number of fish, uncertain exposure, poor reference site selections, the presence of confounding factors and poor or incomplete reporting of data (Fish Survey EWG 1997). The Fish Survey EWG recommended a number of improvements to the fish survey including: the selection of appropriate sentinel species such as small-bodied (presumably more sedentary) fish, study design and sampling to ensure required numbers of fish are collected. As well, a decision tree was developed to help assess whether the fish survey or an alternative is appropriate at a site (Fish Survey EWG 1997).

In Cycle 2, the success of the fish survey was greatly improved in freshwater receiving environments but some key issues remain for fish surveys conducted in marine and estuarine environments. In this issue, Munkittrick et al. (2002) review the results of freshwater fish surveys for Cycle 2, examine general response patterns and national trends as well as problems encountered and lessons learned. They indicate the fish survey for Cycle 2 benefited from an increase in site-specific knowledge, improvements of study design, and the increased experience of companies conducting the assessments. Munkittrick et al. (2002) report that statistically significant differences in gonad size, liver size and condition factor were found for the majority of cases and that similar effects were often correlated among sexes and both fish species surveyed. Further details of this assessment are found in Munkittrick et al. (2002).

The assessment of fish surveys from mills discharging to marine and estuarine environments for Cycle 2 are reported in this issue by Courtenay et al. (2002). Unique difficulties were found with conducting the fish survey in these complex environments such as lack of fish, high dilution of effluent trapped plumes, migratory sentinel species, unsuccessful tracers, confounding factors and problems associated with dredging and shipping (Fish Survey EWG 1997). More than half of the estuarine and marine mills were exempted from the fish survey as a result of difficulties encountered during Cycle 1 that could not be resolved in Cycle 2. For the fish surveys that were conducted, Courtenay et al. (2002) report that much progress in methodologies was made between Cycles 1 and 2.
for assessing impacts of pulp mill effluents on fish in estuarine and marine environments. They discuss the successful use of small-bodied fish in some studies but indicate there is a need for more information on their range of movement, variability and technical guidance for appropriate sampling. Five of the marine and estuarine mills conducting the fish survey used molluscs. Although significant progress was made in Cycle 2 on the use of molluscs for the fish survey, Courtenay et al. (2002) indicate not all endpoints required for the fish survey were measured. Details of these studies are discussed in Courtenay et al. (2002).

Seven mills used alternative approaches to the fish survey such as caged bivalves, mesocosms and one onshore bioassay using bivalves. These are further discussed in Courtenay et al. (2002) and Dubé et al. (2002) in this issue and later in this paper.

Effects on Fish Habitat: Invertebrate Community Survey

The objective of the invertebrate community survey (ICS) is to delineate the magnitude and spatial extent of habitat degradation due to organic enrichment or other forms of contamination, and to provide an evaluation of the aquatic food resources available for fish selected as sentinel species in the fish survey (AEEMR 1992; EC/DFO 1993, 1995b; Environment Canada 1998). However, without a direct comparison between fish diet and benthic invertebrate fauna, the ICS is mainly aimed at examining habitat degradation. As such, the goal of the ICS is to determine structural differences in invertebrate communities in areas receiving pulp mill effluent (Environment Canada 1998).

The intent of the first cycle of EEM was to characterize the benthic invertebrate communities in major habitats that may be affected by mill effluent and to establish a baseline against which future cycles can be compared. Data gathered from Cycle 1 are also used in power analysis for subsequent cycles to determine appropriate sample sizes (Environment Canada 1998). The intent of EEM in subsequent cycles is to compare the results of the previous cycle, help refine monitoring techniques as needed, define the spatial extent of any detected effect, and determine the factors leading to this effect (Environment Canada 1998).

Results from Cycle 1 indicated that 69% of pulp mills found differences between reference and exposure sites for the endpoints of species richness and abundance. However, data interpretation was often confounded by factors such as multiple effluent discharges, inappropriate reference site selection, and lack of standardized methodologies for sampling and data analyses (Benthic Invertebrate Community Survey EWG 1997; Glozier et al. 2002). To address this issue, the Benthic Invertebrate Community Survey EWG (1997) recommended changes in the survey design based on site-specific considerations through the use of a decision tree. A number of recommendations were also made by this EWG to standardize sample collection, processing, taxonomic identification, statistical analysis and reporting, which were incorporated into the Technical Guidance Document (Environment Canada 1998). As well, the reference condition approach (Reynoldson et al.
1997, 2000; Rosenberg et al. 2000) was recommended as an option to the traditional benthic community survey, where appropriate. Glozier et al. (2002) further discuss the development of ICS for the EEM program in Canada.

Preliminary analysis of Cycle 2 indicates the majority of mills reported statistically significant differences in benthic invertebrate communities between exposure and reference areas although many mills found confounding influences contributed to these differences (Environment Canada 2001a). The majority of mills that did find a change in benthic communities also saw an improvement in conditions in the exposure areas when compared with monitoring data from Cycle 1. This decrease in effects on fish habitat, as measured by the benthic ICS, is likely attributed to improvements in effluent treatment. For mills that detected negative changes, confounding factors such as municipal effluents are suggested to have potentially contributed to detected effects. An in-depth assessment of EEM data is currently underway which will provide a more comprehensive analysis of the ICS (R. Lowell, National Water Research Institute, Environment Canada, pers. comm.).

Alternative Monitoring Approaches

The Cycle 1 science review indicated that EEM studies need to allow for alternatives due to site-specific conditions such as confounding factors or the capture of insufficient numbers of appropriate species which prevent mills from conducting effective fish and benthic invertebrate community surveys. To address this issue, alternative monitoring approaches have been developed where site-specific conditions render the standard surveys ineffective. Both mesocosm and caged bivalve studies have been undertaken as alternatives in connection with EEM studies.

Mesocosms

On-site mesocosm test systems or artificial streams (Culp and Podemski 1996; Culp et al. 1996, 2000; Dubé et al. 2002) are now included as appropriate alternatives for both the fish and benthic invertebrate community surveys. The EEM mesocosm study is a comparison of the same general endpoint categories as for the fish and benthic invertebrate community survey among replicated mesocosms that mimic reference conditions and mesocosms that mimic near-field exposure conditions (Environment Canada 2000a). These mesocosms provide effective alternatives for obtaining ecologically relevant data on exposure to effluents in situations where confounding factors (i.e., multiple discharges, historical contamination or complex environments) render standard field surveys ineffective. Mesocosms can examine responses of food webs to stressors by eliminating confounding factors as well as by assessing causative relationships (Culp et al. 2000). The development and application of mesocosms for EEM is further discussed in Dubé et al. (2002) in this issue.

In Cycle 2, much progress was made in developing and testing the use of mesocosms as alternative approaches for EEM. For Cycle 2, three
mills used mesocosms for assessing effects of pulp mill effluent on fish in marine and estuarine environments in eastern Canada (Dubé et al. 2002). Dubé et al. (2002) indicate that mesocosms can be used in subsequent EEM studies to examine the magnitude and spatial extent of the effect, or investigate cause(s) of the effect. Guidance on the use of mesocosms for EEM is available in Environment Canada (2001b).

**Caged bivalve studies**

In situ experiments using caged bivalves under field conditions are also included as an accepted alternative to the fish survey. This approach involves the collection of field data on caged bivalves on both chemical exposure and associated biological effects on the same organism under environmentally realistic conditions. As with mesocosms, the endpoints for caged bivalves are similar to those of a traditional field fish survey. In addition, relative potency is established by comparing tissue levels with effect levels for various chemicals with toxicity and bioaccumulation endpoints (Salazar and Salazar 2001).

Much progress was made in Cycle 2 on using caged bivalves as an alternative to the fish survey. Three mills in western Canada and one mill in eastern Canada conducted caged bivalve studies in Cycle 2. The target endpoints for the caged bivalve studies are survival, growth and condition. While reproduction is considered a key endpoint for the fish survey, there are currently no standardized methods to monitor this endpoint for bivalves (Environment Canada 2001b). Guidance on conducting in situ experiments using caged bivalves has recently been developed for use in EEM studies (Environment Canada 2001b).

**Usability of Resources**

**Tainting**

The tainting study assesses changes in the taste or odour of fish as a result of exposure to pulp and paper effluent as a measure of effects on the usability of fisheries resources by humans. Tainting studies at a mill are triggered by the registration of public complaints or by evidence of tainting in previous monitoring. For Cycle 1, a number of study design problems were identified including various confounding factors that potentially affected the taste of fish including mixing of fish between exposure and reference sites, collection of fish from different habitats, and the influence of contaminants from sources other than the mill (Usability of Resources EWG 1997). As well, a number of concerns were identified with the sensory tests including training of panelists and standardization of procedures. Further, the preference and triangle tests were found to be inappropriate for the purposes of assessing tainting associated with pulp and paper mill effluents. Detailed methodological guidance on conducting tainting evaluations using a Difference-from Control Test including fish collection and processing, acceptable sample sizes and panelist training are now included in the guidance for EEM (Environment Canada 1998).
These methodological changes resulted in more effective sensory evaluations for Cycle 2 and resulted in more interpretable data by providing measures of both presence and intensity of taint (J. Boyd, Pacific and Yukon Region, Environment Canada, pers. comm.). For Cycle 2, only two mills conducted a tainting study. In both cases tainting was confirmed but in only one case was the mill identified as the cause of taint. In this latter case, measures are underway to mitigate the problem (Environment Canada 2001a).

**Analyses of dioxins and furans in edible fish tissue**

Analyses of dioxins and furans in edible fish tissue are also used to assess effects on the usability of fisheries resources for human consumption for mills that use chlorine bleaching. Levels of dioxins and furans in edible fish tissue were low in Cycle 1 as a result of a number of process and treatment strategies implemented by the industry to eliminate dioxins and furans from their effluents (Dioxins EWG 1997). There were, however, a number of technical concerns with the data including species selection for tissue analysis, the lack of standardized analytical methodology and reporting, and the quality assurance/quality control (QA/QC) of the data (Dioxins EWG 1997). Detailed guidance recommended by the Dioxins EWG (1997) to correct these concerns is now incorporated in the Technical Guidance (Environment Canada 1998).

Mills meeting certain conditions were exempted from dioxins and furans analyses in Cycle 2 (see Environment Canada 1998). As such, only ten mills conducted fish tissue analyses for dioxins and furans in Cycle 2, six of which had levels of dioxins and furans in fish tissue that exceeded Health Canada fish consumption guidelines (Environment Canada 2001a).

**Sublethal Toxicity Testing**

Each mill is required to conduct specific sublethal toxicity tests on fish (early life stage development), invertebrate reproduction, and plant toxicity. The Toxicology EWG (1997) reviewed the sublethal toxicity testing results from Cycle 1 and identified issues with respect to sample collection, test methodology and data interpretation. This group recommended all sublethal toxicity tests be continued with the exception of the *Lemna minor* and sheepshead minnow tests. As well, they recommended a 7-day topsmelt survival and growth toxicity test for the west coast marine environment. Recommendations were also made to refine methods and clarify specific toxicity tests, which have been incorporated into the Technical Guidance Document (Environment Canada 1998).

The overall quality of the toxicity tests were generally improved for Cycle 2 with the recommended changes to test methodologies as well as QA/QC reporting. Further, toxicity test results for all three species indicated an overall improvement in effluent quality for Cycle 2 due to the adoption of secondary treatment at most mills. Results from Cycle 2 EEM sublethal toxicity testing are further discussed in Scroggins et al. (2002).
Tracers

The use of a tracer was required in EEM studies, where applicable, to assess fish exposure to mill effluent. The Tracer EWG (Ali et al. 1997) found that a number of technical and operational factors prevented conclusions being drawn as to whether fish were exposed to effluent in Cycle 1. The main issue was poor selection of chemical tracers that were either near or below detection limits. As well, there were inconsistencies among the analytical laboratories on the chemical measurements reported, low sample sizes (i.e., single composite) and little information on chemical concentrations in the effluent to compare with concentrations observed in the fish. Ali et al. (1997) recommended selection of appropriate chemicals for tracers, field validation studies, and sampling and analyses methodologies to improve the use of tracers in EEM studies. These changes have been incorporated into the Technical Guidance for EEM (Environment Canada 1998) and resulted in better tracer selection for Cycle 2. Research is currently underway to explore the potential use of stable isotopes as tracers for EEM studies (M. Dubé, Environment Canada, pers. comm.).

Follow-Up Actions to EEM

Environment Canada (2000b), in consultation with Fisheries and Oceans Canada, has developed guidance for determining follow-up actions when effects have been identified in EEM. Once an effect is identified and confirmed to have been caused by the mill effluent, the EEM program requires the industry to determine the magnitude, geographic extent, and possible cause(s) of the effluent-related effect. Environment Canada (2000b) indicates that effects that compromise the sustainability of fisheries resources should be distinguished from those that do not. Effects on the use of fisheries resources (i.e., tainting, dioxins and furans in edible fish tissue) clearly compromise the present use of fisheries resources, are considered unacceptable, and corrective action is required. However, while changes in measurements for fish and fish habitat will represent scientifically defensible differences or gradients that may reflect changes in ecosystems associated with pulp mill effluents, these changes may not necessarily compromise the sustainability of fisheries resources. It is difficult to develop national criteria specifying which effects on fish or fish habitat will require corrective action, due to the variety of effects and aquatic ecosystems and the diversity of social, economic, and technological factors across Canada.

Therefore, the decision on what follow-up action is required will be based on a site-specific evaluation of ecological, social, economic and technological considerations, conducted outside of EEM. The ecological significance of effects measured in EEM should be evaluated using a weight-of-evidence approach. For example, factors that should be considered include the magnitude, type and geographic extent of effect measured, species affected, temporal trends, etc. Social issues should be considered in consultation with all stakeholders. A weight-of-evidence approach will be
used in determining how acceptable the effect is to local stakeholders. Economic and technological considerations will include a review of technologies available to alleviate the effects as well as the costs associated with implementing those technologies (Environment Canada 2000b).

**Future Directions for EEM**

As a result of a number of data gaps identified during the Cycle 1 review, research areas were identified, some of which are currently being undertaken within the Canadian departments of Environment and Fisheries and Oceans and in collaboration with the pulp and paper industry.

For the fish survey, one of the key areas of research is to address the issue of appropriate sentinel species for reference and exposure sites through assessment of the mobility and residency of fish species in large rivers and estuaries. Another key research need identified was the use of forage or small-bodied fish for EEM. Reproductive development of forage fish is currently being examined in southern Ontario. As well, another study is undertaking a comparison of population response patterns between small- and large-bodied fish species. To help address the issue of obtaining sufficient sample sizes for the fish survey in areas with low abundance of fish, non-lethal sampling methods for estimating fish performance are under investigation in order to further support the use of this sampling method for EEM. McMaster et al. (2002) further discuss collaborative research projects for the fish survey.

A number of research studies are currently underway to address emerging environmental issues. Test methods are under development to assess immunological stress in mussels and mummichogs in coastal waters. As well, an interlaboratory comparison is underway to assess the use of circulating steroid hormone levels for EEM studies. Endocrine disruption studies are being conducted on wild fish and fractions of mill effluent to assess the effect of pulp and paper mill effluent on this endpoint. As well, a comparison of fish and invertebrate responses measured in EEM surveys is being undertaken to assess the relationships among endpoints for various species. A study is also underway to assess the cumulative effects of stressors on the St. John River.

To address the need for alternatives at sites where confounding factors prevent the use of the traditional fish survey, mesocosm technologies are being further developed as an alternative for EEM. Future mesocosm research areas that have been indicated as priorities include a comparison of endpoint sensitivities among trophic levels and an assessment of the application of life-cycle bioassays. As well, a comparison is needed of the mesocosm approach with other field assessment approaches.

Areas for future research were also identified and prioritized following Cycle 1 and further focused following the end of Cycle 2. For example, research is needed to assess the degree to which effects found using EEM can be ascribed to mills versus other confounding factors including: the development of new monitoring designs, new laboratory and field experimental approaches, and the development of qualitative probabilis-
tic methods relating exposure to effects to perform cumulative risk assessments. As well, further work is needed to determine critical effect sizes and to integrate EEM data with other databases to evaluate patterns and trends in aquatic biodiversity. Work is also needed on endpoint development in whole-body fish sex steroid determinations. Within the area of sublethal toxicity testing, toxicity identification evaluations are needed for the sea urchin fertilization and *Champia parvula* toxicity tests.

To date, EEM for pulp and paper mills has been able to incorporate advances in science and technology to ensure the monitoring program is continually improved based on best available science. EEM will continue to improve to ensure the program incorporates advances in science, is able to address emerging environmental issues, and ensure data are generated in a timely manner to provide a national perspective on the effects of pulp and paper mills on aquatic environments. These data will be a key component in the assessment of the adequacy of the PPER to protect fish, fish habitat and the use of fisheries resources.

In the articles in this special EEM volume, preliminary analysis of Cycle 2 data are presented and various topics of relevance to the pulp and paper EEM program are discussed. As well, Environment Canada is currently in the process of validating and conducting an in-depth national assessment of the EEM data generated to date.

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